

Detection of FeO towards SgrB2

C.M. Walmsley

Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy

walmsley@arcetri.astro.it

R. Bachiller

Observatorio Astronómico Nacional (IGN), Campus Universitario, E-28800 Alcalá de Henares (Madrid), Spain

bachiller@oan.es

G. Pineau des Forêts

IAS, Université de Paris-Sud, Bat. 121, F-92405, Orsay, France

forets@mesio.b.observatoire.fr

and

P. Schilke

Max Planck Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany

schilke@mpifr-bonn.mpg.de

ABSTRACT

We have observed the J=5-4 ground state transition of FeO at a frequency of 153 GHz towards a selection of galactic sources. Towards the galactic center source SgrB2, we see weak absorption at approximately the velocity of other features towards this source (62 km s^{-1} LSR). Towards other sources, the results were negative as they were also for MgOH(3-2) and FeC(6-5). We tentatively conclude that the absorption seen toward SgrB2 is due to FeO in the hot ($\sim 500 \text{ K}$) relatively low density absorbing gas known to be present in this line of sight. This is the first (albeit tentative) detection of FeO or any iron-containing molecule in the interstellar gas. Assuming the observed absorption to be due to FeO, we estimate $[\text{FeO}]/[\text{SiO}]$ to be of order or less than 0.002 and $[\text{FeO}]/[\text{H}_2]$ of order 3×10^{-11} . This is compatible with our negative results in other sources. Our results suggest that the iron liberated from grains in the shocks associated with SgrB2 remains atomic and is not processed into molecular form.

Subject headings: ISM: individual(Sagittarius B2) —ISM: molecules — ISM: abundances

1. Introduction

The failure to discover iron-bearing molecules in the interstellar medium is a long standing puzzle. It is related to the general problem of the depletion of refractory elements (see e.g. Jenkins 1989, Weingartner and Draine 1999, Walmsley et al. 1999, Walmsley 2000) within both diffuse and dense molecular clouds. There is good evidence that the degree of depletion is correlated with density in diffuse clouds and that it is extremely high within molecular clouds. In fact, the abundance of gas phase silicon appears to be six orders of magnitude below the solar Si abundance in some circumstances (see also Ziurys, Friberg, & Irvine 1989). Moreover, Turner(1991) has put limits on the abundance of a variety of molecules containing Na, Si, Mg, Fe, and P showing that the case of silicon is not unusual. The refractory elements thought to be the main constituents of “silicate grains” are even more underabundant in the gas phase of dense molecular clouds than they are in the diffuse medium sampled by UV observations.

Nevertheless, silicon (essentially in the form SiO) is known to be present at a low level in some molecular clouds associated with outflows (see Bachiller and Tafalla 1999, Bachiller et al. 2001, Codella et al. 2001) as well as in photon dominated regions (PDRs, Schilke et al. 2001). The general interpretation of this is that a small fraction of Si is returned to the gas phase in shocks associated with star formation in molecular clouds (see e.g. Caselli, Hartquist, & Havnes 1997, Schilke, Pineau des Forêts & Walmsley 1997). One might therefore naively expect iron and magnesium to be also liberated in such shocks and hence to be present in the molecular gas phase at the same low level. With this in mind, we have started an observational program searching for Mg/Fe containing species associated with shocks.

This article describes a small search carried out with the IRAM 30-m telescope for iron and magnesium containing species. In the course of this, we detected evidence for the presence of FeO in the molecular clouds seen in absorption along the line of sight towards the continuum source in the vicinity of the galactic center SgrB2-M. SiO is well known along this line of sight (Greaves, Ohishi, & Nyman 1996, Hüttemeister et al. 1995, Peng, Vogel, & Carlstrom 1995) and indeed is more abundant in galactic center clouds in general (Hüttemeister et al. 1998) than in molecular clouds in the solar vicinity. The observed large line widths suggest that this may be due to shocks (e.g. Flower, Pineau des Forêts & Walmsley 1995) caused by cloud–cloud collisions due to shearing motions in the inner Galaxy.

It is also possible that the chemistry is affected by the hard X-ray sources in the vicinity of SgrB2 which heat and ionize the neighbouring molecular clouds (see Martin–Pintado et al. 2000). In any case, one expects a correlation between silicon and iron and hence it is reasonable to expect to find traces of FeO in such regions. In this letter, we present the evidence that FeO has been detected in the interstellar medium and briefly mention some consequences for the chemistry of iron in molecular clouds.

2. Observations

The main body of our observations were carried out at the IRAM 30-m telescope on Oct. 14 2001 and confirmatory observations towards SgrB2 were carried out on Dec. 1 2001. We observed (in October) using four receivers simultaneously tuned to the frequencies of MgOH(3-2) (88.932268 GHz; the average of the doublet frequencies, Ziurys et al. 1996), FeO 5-4 ($\Omega = 4$, Allen, Ziurys & Brown 1996, 153135.273 MHz), FeC(6-5) (240862.951 MHz), and MgOH(9-8) (266.728845 GHz). We used the wobbler beam switch with a throw of 4 arc minutes. The facility SIS receivers were used tuned in single sideband mode with image rejections of order 10dB.

As spectrometers, we had available at all frequencies filterbanks with 1 MHz channel spectral resolution and 256 MHz bandwidth. We also used the autocorrelator split into 5 parts. For the 153 GHz FeO line which is the main theme of this article, we used a resolution of 320 KHz and a bandwidth of 80 MHz. Pointing checks were taken at intervals of roughly 2 hours during the observations and showed deviations less than or of order 5". The angular resolution of the IRAM 30-m telescope varies from 27" at 88 GHz to 16" at 153 GHz to 10" at 240 GHz and 9" at 266 GHz. The corresponding beam efficiencies vary between 0.78 at 88 GHz to 0.68 at 153 GHz, 0.5 at 240 GHz, and 0.45 at 266 GHz. The forward efficiencies vary between 0.95 at 88 GHz to 0.93 at 153 GHz and 0.9 at 245 GHz.

On Dec. 1, we observed (remotely from Bonn) only SgrB2-M and pointed on that source. We observed simultaneously FeO(5-4) and FeO(8-7) (244992 MHz, HPBW 10") in wobbler switch mode with a throw of 4'. The 1 MHz filters were used.

3. Observational Results

We list the sources and positions observed in table 1 where we give on the scale of T_A^* the RMS noise in mK. One can convert to main-beam brightness temperature multiplying by the ratio of forward and beam efficiencies. The results were negative with the exception

of the spectra in FeO towards SgrB2-M and we now discuss this observation. We note that the FeO(5-4) ($\Omega = 4$) frequency which we have used differs by roughly 6 MHz from that employed in the FeO survey of Merer, Walmsley, & Churchwell (1982).

Figure 1 (top panel) shows the spectra taken with the filterbank towards SgrB2-M. One sees the $9_{09} - 8_{18}$ quadruplet of transitions of dimethyl ether at 153056 MHz as well as a line at 153226 MHz (probably HCOOCH_3 $28_{1,27} - 28_{0,28}$) and a weak unidentified feature at 153162 MHz. We superpose the October (thin line, integration time 36 min. total on plus off) and December (bold, integr. time 68 min.) spectra for comparison. We observe on both dates weak absorption at approximately the FeO frequency which stretches over the velocity range 35-75 km s^{-1} . The Dec.1 spectrum is reasonably fit with a component of width 11.3 km s^{-1} and velocity 61.3 km s^{-1} . The October spectrum also shows traces of a broader feature which the Dec.1 data do not confirm and which we presently consider to be instrumental. The narrower feature however is present in both spectra at the same velocity confirming to us that this is an astronomical feature and not, for example, of atmospheric origin. The features at 153162 and 153226 MHz are also seen in our spectrum towards Orion-KL though not towards IRC10216 suggesting to us that they are neither FeO nor carbon-rich species. Neither feature was detected in the FCRAO 14-m survey of Ziurys and McGonagle (1993) suggesting that the emission is compact.

Figure 1 (center and lower panels) also shows spectra in SiO(2-1) and $^{29}\text{SiO}(2-1)$ taken by de Vicente (1994) with the IRAM 30-m telescope toward SgrB2 with a HPBW of 27". One sees that the velocity of peak absorption is at 61.5 km s^{-1} for both $^{29}\text{SiO}(2-1)$ and FeO(5-4) whereas $^{28}\text{SiO}(2-1)$ has its peak absorption at higher velocities. On the other hand, ^{29}SiO only shows a narrow (15 km s^{-1} wide) absorption line in contrast to (optically thick) ^{28}SiO .

We have estimated the area under the “FeO absorption” seen in Fig. 1 as -1.0 K km s^{-1} (in T_A^* units integrating just over the narrow feature with an error of at least 50 percent mainly dependent on the baseline placement). The continuum offset we derive relative to the reference position is 2.2 ± 0.3 K leading to an integrated line-to-continuum ratio of 0.5 km s^{-1} with similar uncertainty. We checked for contamination on the reference position by comparing with a position switched scan with reference 1800" away and found no difference within the errors. We also checked for “FeO” emission at positions 20" offset and found no emission greater than 0.15 K. We conclude therefore that we are observing true absorption against the continuum background of SgrB2-M. However, our search for FeO(8-7) towards SgrB2 was negative down to a limit of 0.4 K (3σ) in T_A^* units.

The likelihood that we have detected FeO in absorption seems high. In the first place, the agreement with the expected line frequency is reasonable. There is good agreement with ^{29}SiO and for ^{28}SiO a difference in the peak of the absorption of 4 km s^{-1} ($v=61$ km

s^{-1} rather than $v=65 \text{ km s}^{-1}$ seen in $\text{SiO}(2-1)$). While this difference of $\sim 2 \text{ MHz}$ is well outside the uncertainties in the laboratory rest frequencies, the ^{29}SiO result suggests that it is caused by high SiO optical depth (see Peng et al. 1995). Secondly, the $\text{FeO}(5-4)(\Omega = 4)$ transition observed by us is a ground state transition (see Merer et al. 1982) and thus it is plausible that one observes absorption towards a strong continuum source such as SgrB2-M. Absorption towards SgrB2 has been seen in many transitions from the cm range (Winnewisser, Churchwell, & Walmsley 1979) to the FIR (Ceccarelli et al. 2001) and this is attributed generally to the presence of a relatively low density ($n(\text{H}_2) \sim 10^4 \text{ cm}^{-3}$) hot (500K) foreground layer (see e.g. Flower et al. 1995). We suspect that we are observing absorption by FeO associated with this gas. The FeO 5-4 transition has a critical density of order 10^6 cm^{-3} (Merer et al. 1982 using a dipole moment of 4.7 Debye from Steimle et al. 1989) and thus it seems reasonable to assume that in this foreground layer, FeO is predominantly in the $J=4$ ground state. This is completely consistent with our negative results in $\text{FeO}(8-7)$. Using a crude LVG program and supposing collisional deexcitation rates of order $10^{-10} \text{ cm}^3 \text{ s}^{-1}$, we estimate a ratio of roughly 100 between the optical depths of the two transitions if the density is 10^4 cm^{-3} . This implies an effective optical depth in $\text{FeO}(8-7)$ less than 10^{-3} .

We note finally that another possible identification might be the $\text{AlO}(4-3)$ transition which consists of roughly 30 components spread over the range 152987 to 153251 MHz. This seems to us unlikely. The pattern does not fit well with the observed profile and there is no evidence of an analogous feature of $\text{AlO}(6-5)$ in the data of Nummelin et al. (1998).

4. Analysis

Based on the results of the previous section, we now use equation 2 of Merer et al. to infer the column density of FeO in the putative foreground layer. We conclude on this basis that the column density $N(\text{FeO})$ (dipole moment of 4.7 Debye from Steimle et al. 1989) is given by :

$$N(\text{FeO}) = 1.9 \cdot 10^{12} \int \tau dv \text{ cm}^{-2} \quad (1)$$

where τ is the optical depth (assumed small) and v is the velocity in km s^{-1} . We also assume here that the FeO level populations are determined by the cosmic 3 K background consistent with our negative result in $\text{FeO}(8-7)$.

We conclude that our results are compatible with a FeO column density of order 10^{12} cm^{-2} . The SiO column density on the other hand (Peng et al. 1995) is at least $5 \times 10^{14} \text{ cm}^{-2}$

and thus we have $[\text{FeO}]/[\text{SiO}]$ of order 0.002. The column density of H_2 in the absorbing layer is poorly known (see Flower et al. 1995) but taking a compromise value of $3 \times 10^{22} \text{ cm}^{-2}$, we estimate that $[\text{FeO}]/[\text{H}_2]$ is approximately 3×10^{-11} .

This is still a tiny fraction of the solar iron abundance (4×10^{-5} relative to H) and the obvious question is whether FeO is the most abundant gas phase iron component in this hot absorbing layer or not. Little is known about the chemistry of iron-bearing molecules but the frequency sweeps presently available (e.g. Nummelin et al. 2000) have not given evidence for molecules containing Fe. Clearly however, searches for species such as FeH are warranted and other oxides or hydroxides may be important gas phase repositories of iron. We note however that our negative results for FeC towards SgrB2 may not be very significant if, as we suspect, only the lowest rotational levels are populated in the layer which we believe we are detecting in FeO towards SgrB2.

Our results towards other sources tell a rather similar story. One may take the case of L1157 as an example where our results put a limit of 30 mK (integration time 114 minutes on plus off source, intensity in main-beam brightness units) on any FeO(5-4) line towards the blue-shifted SiO peak (B1 in the nomenclature of Bachiller and Pérez Gutiérrez 1997). For an assumed line width of 10 km s^{-1} , we derive an upper limit for the FeO column density of $6 \times 10^{11} \text{ cm}^{-2}$ (assuming an excitation temperature below 50 K). The SiO column density in this position is $8 \times 10^{13} \text{ cm}^{-2}$ and so we conclude that also towards L1157(B1), one has $[\text{FeO}]/[\text{SiO}]$ less than 0.01.

In order to interpret this result, we have constructed a small model of iron chemistry in a shock using an updated version of the model described by Schilke et al. (1997). This assumes that gas phase iron is eroded from grain surfaces due to sputtering in the shocked gas (May et al. 2000). We find that while the erosion rates are similar for iron and silicon, gas phase iron is much less reactive in the shock and in the post shock gas than atomic silicon. This is basically due to the fact that while atomic silicon can react at low temperatures with species such as OH and O_2 , the analogous reactions for atomic iron (endothermic by 10200 K for $\text{Fe} + \text{O}_2$ and 1550 K for $\text{Fe} + \text{OH}$) only occur under high temperature conditions in a shock. As a consequence, it seems quite plausible that a few percent of the eroded iron atoms are processed into molecular form while essentially all of the eroded silicon suffers this fate. We will describe these results elsewhere but our provisional conclusion is that the observed ratio $[\text{FeO}]/[\text{SiO}]$ is explicable in this fashion. Another interesting result is that a considerable fraction of the FeO produced in this manner can be further processed to FeOH due to the (endothermic) reaction with H_2 .

5. Conclusions

We believe that we have detected FeO in absorption towards SgrB2. However, the feature which we have detected is weak and more confirmatory measurements are needed. Searches for other low excitation transitions of iron-bearing species would be useful. A more detailed study of the interstellar chemistry of iron is also needed.

Even if our identification in SgrB2 turns out to be incorrect, one can conclude that in the SgrB2 absorbing layer as well as in the post-shock gas which one observes towards L1157, one has $[\text{FeO}]/[\text{SiO}]$ less than 0.01. SiO is thought to be a major form of gas phase silicon and thus the SiO abundance gives a measure of silicon depletion. For FeO, the preliminary model calculations mentioned earlier suggest that iron is indeed produced by erosion in shocks but remains atomic in the post-shock medium. Indeed [FeII] emission is well known in the shocks associated with the Orion outflow (Tedds, Brand, & Burton 1999) and so this is quite plausible. We conclude therefore that erosion of silicate grains in high velocity (40km s^{-1}) shocks is a plausible explanation of our observation towards SgrB2.

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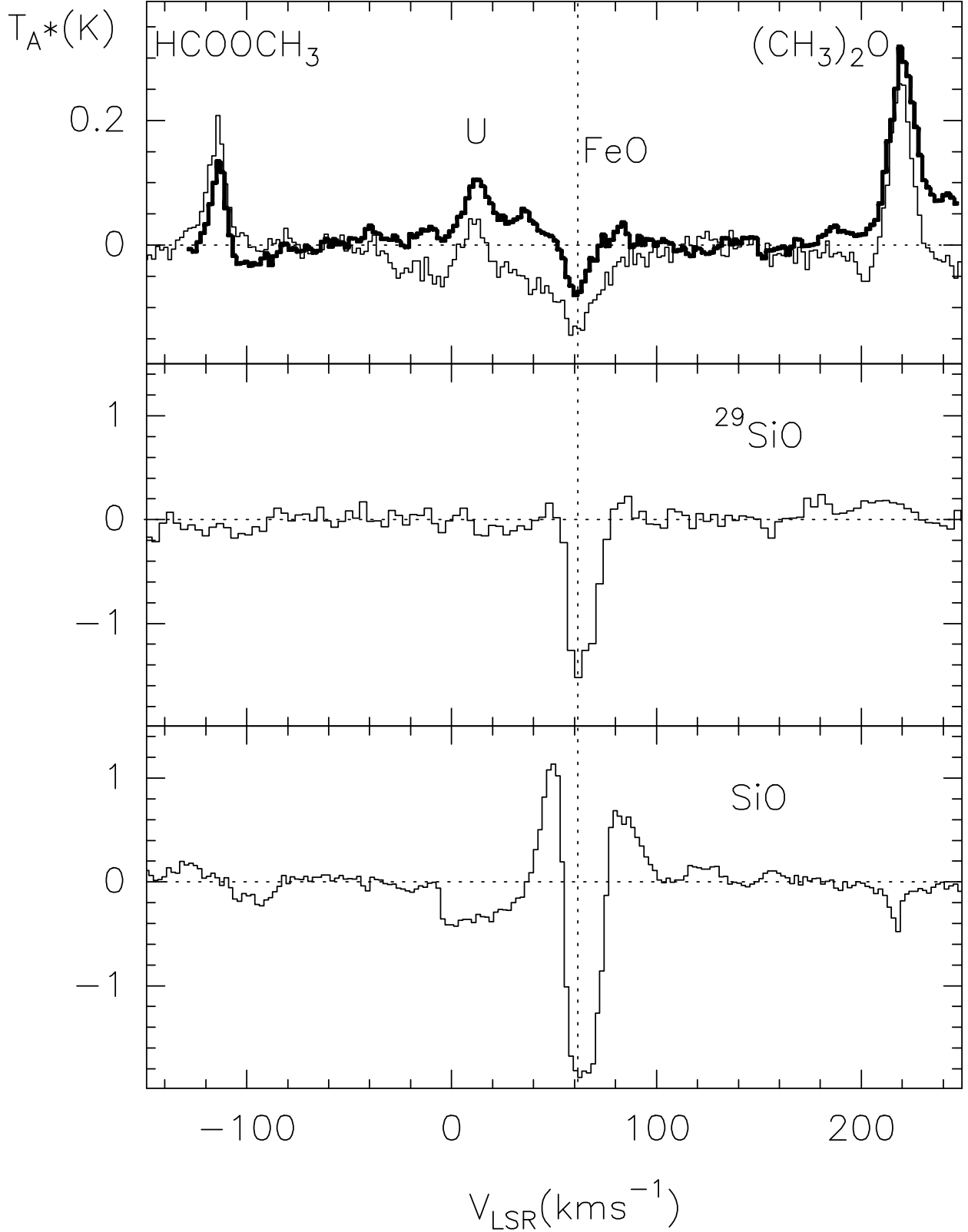


Fig. 1.— The top panel shows the FeO 5-4 ($\Omega=4$) spectrum toward SgrB2-M (1950 coordinates : R.A. = $17^{\text{h}} 44^{\text{m}} 10.3^{\text{s}}$, Dec. = $-28^{\circ} 22' 04''$, full line shows the October spectrum and bold line the Dec.1 measurement). The middle and lower panels show the 2-1 lines of ^{29}SiO and SiO , near 85.759 and 86.846 GHz, respectively, also observed with the IRAM 30-m telescope (from Viti et al. 1994). A dashed line at 61.5 km s^{-1} indicates the velocity of the

Table 1: Sources and RMS(Noise) for observations of FeO(5-4), FeC(6-5), and MgOH(3-2)

Source	R.A. (1950)	Dec. (1950)	Vel.(LSR)	RMS (FeO) ^a	RMS(FeC) ^a	RMS(MgOH) ^a
	<i>h m s</i>	<i>° ′ ″</i>	km s ⁻¹	mK	mK	mK
W3(OH)	02 23 16.5	61 38 57	-45	21	52	17
Ori-IRc2	05 32 47.0	-05 24 24	7	10	40	7
IC443-G1	06 13 42.0	22 33 40	-10	12	26	7
IRC10216	09 45 14.8	13 30 40	-27	9	16	5
I16293-E2	16 29 27.0	-24 21 36	7	8	25	6
SgrB2-M	17 44 10.3	-28 22 04	65	13	30	17
SgrB2-N ^b	17 44 10.3	-28 21 14	65	70		26
L1157B	20 38 43.1	67 50 31	1	5	10	3

^aNoise Values for 1 MHz resolution

^bSgrB2-N spectrum is so crowded that the "RMS" given for FeO is a measure of confusion due to blended U-lines rather than noise and FeC(6-5) is completely blended with U-lines

Note. — The RMS noise values in columns 5-7 are for FeO(5-4), FeC(6-5), and MgOH(3-2) respectively